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A comprehensive review of metrics of building environmental assessment schemes

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ABSTRACT

Buildings are key target of policies that aim at promoting environmentally sustainable development. Amongst policy instruments that address environmental burdens incurred by buildings, labelling and certification schemes are arguably the most cost-effective. Since the first building environmental assessment scheme was launched in the 1990's, similar schemes have emerged in about 30 countries. These are mainly domestic schemes tailored to suit local contexts. Whilst most of these schemes take a voluntary, market driven approach, some have become a part of mandatory building approval requirements, though different certification schemes may co-exist in some regimes. Benchmarking the strengths and characteristics of different schemes has been advocated. In this connection, this paper provides a comprehensive review and comparison of the issues and metrics of five representative assessment schemes, namely, BREEAM, LEED, CASBEE, BEAM Plus and the Chinese scheme ESGB. Comparison of these five schemes shows that BREEAM and LEED are the most comprehensive. A two-phase certification method is adopted in LEED, CASBEE and BEAM Plus, which is considered preferable. Statistical analysis also reveals that there is a moderate degree of agreement amongst the five schemes on weights and ranks of weights allocated to five key assessment aspects. Through comparison, the weighting coefficients adopted by ESGB were found the most representative. Strengths and characteristics of the five schemes have been identified for reference of policy makers in developing their domestic schemes.

1. Introduction

Voluntary building environmental assessment schemes came into prominence in the early 1990s. They are considered an effective instrument and are being widely used to realize substantial reductions in environmental impacts incurred by buildings [1]. They offer flexibility to building owners in reaching targets, thereby improving their image, and are useful to policy makers in raising public awareness, promoting achievements of standards over and above the minimum regulatory requirements and in maintaining dialogue with the private sector [1–4]. Under such schemes, a building is assessed against a set of quantitative and qualitative performance criteria, and is awarded credits (or points or numeric scores) when the building is deemed to have met the specified criteria. Threshold performance (zero credit) levels are often set with reference to standards that correspond to “common practices,” such that awarded credits reflect performance in respect of related criteria. Most assessment schemes now cover comprehensively different aspects relevant to sustainable development of buildings and embrace a wide range of building premises, such as homes, hotels, offices, industrial premises, retail outlets schools, etc.

Over the years, different building environmental assessment schemes have been evaluated and benchmarked against each other in detail. Since the rating system has profound impact on assessment results, attention has been paid in evaluation studies to strategies used for assigning credits for assessed issues in a scheme [4–7]. The issues examined include whether numeric credit scores should be proportional to environmental implications or the costs of abatement measures [8,9]. Allocation of weights to various assessed areas or aspects have also been studied, through soliciting opinions of experts in diverse fields. Whilst many agree that the weights should reflect environmental significance, no consensus has been reached as yet [4,5,10–12]. At the moment, large variations exist in the level of performance and the criteria stipulated for certifications amongst different schemes [13,14]. Whether assessment should be based on “design” or “as-built” performance, “predicted” or “realized” outcomes, and on “environmental” or “financial” impacts, are issues that remain controversial [4,15]. Likewise, whether “rigorous and stringent” or “relaxed and pragmatic” approach should be preferred is also debatable [10]. The assessment issues and parameters are also of concern. These include whether certain issues should be included, such as sustainability, issues beyond the control of building owners, management

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issues, and more scientific quantification of impacts through the use of life cycle assessment (LCA) [15–17].

Despite much having been written about the commonalities and differences amongst different schemes, as well as their merits and demerits, it is noted that such analyses are non-systematic, and comparisons are mostly between two schemes. The focuses are typically confined to technicalities; few have addressed the organizational and market contexts under which the schemes operate to compare their strengths and weaknesses. For instance, in China, there is acute tension between electricity supply and demand, but electricity price is highly regulated [18]. With market forces rendered irrelevant, demand surges have resulted in power-outages in some regions, leading to supply restraints. An assessment based on "financial" impact (as will be the case if LEED is applied) but without a free-market price to reflect the value of electricity will lead to misleading results. Similarly, most schemes put greater emphasis on energy use than water use, but the reverse is true for regimes in the Gulf area. Thus, no conclusive results can be drawn from previous analyses and comparisons.

Being desirous of using building environmental assessment schemes as a vehicle to reduce environmental impacts of buildings, many countries have either developed or are in the process of developing their own assessment schemes. Most new schemes are developed with reference to first generation assessment schemes that originated from developed countries [4]. However, the reference schemes were themselves developed to address specific regional concerns, and were often structured into practical frameworks, which make their reconfiguration for application to another regime a difficult proposition. Hence, whilst there is a growing number of building environmental assessment schemes all over the world, the schemes differ to a great extent in various aspects. It is also common to see different types of schemes coexisting in the same market.

Although most schemes were originally intended to serve as voluntary tools for encouraging enhancement of buildings' environmental performance, compliance with their requirements is increasingly being made a condition for approval of building projects to be constructed by the private sector and non-government organizations. For example, UK government departments require all their buildings to be certified under BREEAM [19]. Similarly, all public building developments in Hong Kong must seek BEAM Plus certification [20]. Several local authorities in Japan have also called for CASBEE certification as part of their building approval requirements [21]. ESGB in China is no exception [22]. LEED certification is increasingly being specified by organizations and public agencies for buildings, both inside and outside US [4,23].

It has been observed that on top of assessment under a domestic scheme, building developments may additionally undergo a LEED assessment. Given the large variations amongst different schemes, both in their complexity and in their application, this largely increases the costs of acquiring certifications, including costs of submission, preparation and hiring experts to conduct compliance checks. Furthermore, assessment results from different schemes cannot be directly benchmarked and compared, and should there be large differences in outcomes of different assessments, suspicion may arise on the credibility of either or both schemes. Thus, systematic benchmarking the strengths and characteristics of different schemes for reference of policy makers in developing domestic schemes for individual regimes has been advocated [24].

Furthermore, instead of making isolated efforts for developing and enhancing individual schemes, it will be desirable for policy makers to familiar with the strengths of different building environmental assessment schemes, which may entail coordination and sharing of research efforts for enhancing the efficacy of schemes of individual regimes.

Amongst building environmental assessment schemes, BREEAM and LEED, both being national schemes at the onset, have been successfully exported to many other regimes. For example, BREEAM has been licensed to European and Gulf countries whilst LEED has penetrated into Canada and India [10]. CASBEE is widely used in Japan, together with BEAM Plus in Hong Kong. How does different schemes benchmark against each other? Finding the answer to this question entails a holistic review of the scope and metrics of these assessment schemes.

2. Review of building environmental assessment schemes

Since BREEAM, the first building environmental assessment scheme, was launched in the early 1990s, there has been a significant rise in the number of building environmental assessment schemes that promote sustainable building developments. The more widely known include the Green Star in Australia, BEPAC in Canada, the Evaluation Standard for Green Building (ESGB) in China, the Eco-Management and Auditing Scheme (EMAS) in the European Union, BEAM Plus in Hong Kong, CASBEE in Japan, GBCC in Korea, SBAT in South Africa, the Green Building Labelling System in Taiwan, and the LEED, CHEERS and Green Building Program in the United States. There is also an international collaboration framework, the SBTool.

Amongst the large number of assessment schemes being used in different regimes, BREEAM from the United Kingdom and LEED from United States are evidently the most widely recognized. They represent the two main streams of methods currently in use across the world and have influenced enormously the development of more recently established schemes [4]. Other developed regimes like Japan and Hong Kong are very conscious about environmental impacts of buildings and they have developed their own schemes which have had significant effects on their respective building industries. The metric system of CASBEE is considered note-worthy [10] whilst BEAM Plus, on a per capita basis, is the most widely used voluntary scheme of its kind in the world [25]. Amongst developing countries, China has a huge potential for contributing to minimization of environmental impacts of buildings through implementing its ESGB. It is also worth noting that BEAM Plus was modelled from BREEAM, whilst ESGB is largely based on LEED. Therefore, reviews of these two schemes can provide a contrast between schemes that are at different stages of development, and show how the developed schemes have been adapted to local contexts.

Accordingly, this review focuses on five building environmental assessment schemes, namely, BREEAM, LEED, CASBEE, BEAM Plus and ESGB. Whilst there are common characteristics amongst these schemes, each places different degrees of emphasis on the range of aspects it incorporates, to suit their respective local contexts. For identifying their similarities and differences, the history, the metrics and the key characteristics of the five schemes are examined.

Note that different schemes use different terminologies to describe the same entity, or the same terminology for different entities, in accordance with their respective local practices. The terms employed in this paper are defined within the context in which they are used.

Whilst for the assessment aspects, the five schemes are structured in different formats, and thus a common basis is required for this comparison. In this study, SBTool 2010 was chosen as the common basis [26]. SBTool 2010 is a second generation assessment scheme designed to permit customization to reflect regional practices and goals. The scheme is the outcome of the Sustainable Building (SB) Challenge. SB Challenge is a continuation of the Green Building Challenge process that began in 1996. The process is supported by a non-profit making organization, the International Initiative for a Sustainable Built Environment (IISBE). The scheme focuses on seven distinct issues of which weights assigned to issues can be adjusted to suit local contexts.

1. Site Suitability and Development
2. Energy and Resource Consumption
3. Environmental Loadings
4. Indoor Environmental Quality
5. Service Quality
6. Social and Economic Aspects
7. Cultural and Perceptual Aspects.

2.1. BREEAM

BREEAM was the first building environmental assessment method launched and operated by the Building Research Establishment (BRE) in the UK [27]. Version 1 of BREEAM for offices was first released in 1993. The second revision, launched in September 1998, covers a range of building types including offices, industrial premises, retail outlets, schools, etc. The latest version is BREEAM New Construction 2011 [28]. BREEAM is the best-known scheme; over 2000 buildings in the UK have been assessed [29]. It served as a reference model for similar schemes developed in Canada, New Zealand, Norway, Singapore and Hong Kong.

The key criteria and features of BREEAM Offices are structured hierarchically into Issues, Categories, and Criteria levels. At the top level, there are ten distinct issues (the maximum number of obtainable credits is shown in parentheses): Management (22), Health & Well-being (14), Energy (30), Transport (9), Water (9), Materials (12), Waste (7), Land Use & Ecology (12), Pollution (13), and Innovation (10). The second level includes 69 categories and the third level covers 114 criteria. The total number of credits for each category was determined by expert opinion [10].

BREEAM adopts the credits scoring system. Credits are awarded for all issues according to the pre-set performance or feature specific criteria. However, credits awarded for the Innovation issue are exemplary. For performance based criteria, both linear and non-linear credit scales are adopted, depending on the characteristics of individual aspects of assessment. Credits awarded for different aspects of assessment are summed to yield a total score for each category and then an overall score, as well as percentage of the maximum achievable score for all categories. The latter is used to determine the overall grade of the assessment, which may be: Pass (≥30%), Good (≥45%), Very Good (≥55%), Excellent (≥70%) or Outstanding (≥85%). No weightings are applied to credits awarded under different categories, as the number of obtainable credits assigned to each category already reflects the weight assigned to a category of assessment relative to other categories. For obtaining BREEAM certification, besides achieving a total percentage score that equals or exceeds the minimum percentage score of an awardable grade, a minimum number of credits is defined for each category of assessment pertaining to each rating level, and the number of credits obtained in individual categories must not be lower than the minimum number of credits specified for a given category.

The scheme can be used to assess an entirely new building, extension of an existing building or a combination of newly built and refurbished parts of an existing building, which may be a large mixed-use building, or building fit-out at the design or post-construction stage. The design stage assessment and the subsequent interim BREEAM certification (based on performance expected on the basis of design parameters) represent the anticipated performance of the building, typically issued prior to the beginning of operations on site. The post-construction assessment and the rating given in subsequent BREEAM certification represents the final “as built” performance. The post-construction assessment, which includes evaluation of operating and actual site measurement data, is meant to confirm the interim BREEAM rating awarded at the design stage, in accordance with the prescribed reporting and evidential requirements.

2.2. LEED

Leadership in Energy and Environmental Design (LEED) was developed by the US Green Building Council (USGBC) for the US Department of Energy. The pilot version (LEED 1.0) of New Construction was first launched at USGBC Membership Summit in August 1998. In March 2000, LEED Version 2.0 based on modifications made during the pilot period was released. Since then, LEED continues to evolve to respond to needs of the market and has been expanded to cover other building types. The current LEED 2009 New Construction (NC) was released in February 2010 [30]. It covers many building types including office buildings, high-rise residential buildings, government buildings, recreational facilities, manufacturing plants and laboratories building types. The latest version of LEED for Existing Buildings: Operations & Maintenance Rating System was released in 2009. So far LEED is the most widely recognized building environmental assessment scheme, with LEED assessments being carried out in 41 countries, including Canada, Brazil, Mexico, India and China.

LEED for New Construction 2009 is structured into two levels, Categories and Points, which are similar to Issues and Categories in other schemes. The points scoring system is used. There are seven categories that cover (maximum number of points for each category in parentheses): Sustainable Sites (26), Water Efficiency (10), Energy and Atmosphere (35), Materials and Resources (14), Indoor Environmental Quality (15), Innovation in Design (6), and Regional Priority (4); the maximum possible total score is 110 points. Innovation in Design credits (IDC) and Regional Priority credits (RPC) are “bonus credits”. IDC is given for exemplary performance that yields significant environmental benefits not covered in the core rating system. RPC is to incentivize the achievement of credits that address geographically specific environmental priorities.

Points are awarded under the seven categories according to different performance or feature specific criteria. Most of the performance based criteria follow a linear scoring scale. The awarded points for individual aspects of assessment are summed and compared against a rating scale to yield an overall grade, which may be certified (40–49 points), silver (50–59 points), gold (60–79 points) or platinum (>80 points). As a condition for earning LEED certification, the applicant project must satisfy all pre-requisites and score a minimum number of points.

By making available separate assessment schemes for different stages of the building life cycle, LEED assessment can be conducted during several phases of a building development project, as well as during the in-use phase. This provides flexibility for considering different levels of control that a developer might have over the building design and the different points of emphasis for new and existing buildings.

LEED for New Construction is applicable to new and major renovation projects where the developers can exert complete control over design. LEED for Core & Shell is for projects where the developer has control over design and construction of the core and the shell, but is not in a position to control the fit-out design and works executed by the tenants. LEED for Commercial Interiors is for improvement of new and existing office spaces carried out for a tenant, to encourage tenants and fit-out designers to make sustainable choices. In these three schemes, there is an option of splitting the certification process into two phases: the design phase and the construction phase. Points awarded in the design phase review are based on performances predicted from available design information. Certification will only be granted after construction is complete and points awarded on the basis of design are verified.

Information and calculations submitted by project applicants are taken as trustworthy; no submission of building performance data is required.

LEED for existing buildings: Operation and Maintenance cover the entire building's cleaning and maintenance related issues. The certification process deviates slightly from those of the other three schemes. It applies to both existing buildings seeking LEED certification for the first time and projects previously certified under LEED for New Construction or Core & Shell. Any first-time application is considered for an initial certification under LEED for Existing Buildings. Previously certified existing buildings are eligible for recertification, which can be sought as frequently as annually, but the developer must file an application for recertification at least once every five years to maintain its certified status under LEED for Existing Buildings. Initial- and Re-certification requires the submission of continuously monitored whole building energy and water usage data for a minimum period of three months to a maximum of two years. However, the performance period cannot have any time gaps longer than one full week.

2.3. CASBEE

The Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) was developed by the Japan GreenBuild Council (JaGBC)/Japan Sustainable Building Consortium (JSBC) and their subcommittees. The first version, CASBEE for office, was completed in 2002, followed by CASBEE for New Construction in July 2003, CASBEE for Existing Buildings in July 2004, and CASBEE for Renovation in July 2005. Since then, the working group continues to compile different CASBEE tools to cover almost all building types from new construction to renovation and from urban development to independent houses. Consequently, environmental performance assessment of buildings is now carried out for many buildings in Japan. The latest version of CASBEE for New Construction is the 2010 Edition [31]. CASBEE takes into consideration issues and problems peculiar to Japan and Asia, and has been treated as a reference model for developing the Green Olympic Building Assessment System (GOBAS) for Beijing Olympics 2008 [32].

The key criteria and features of CASBEE for New Construction are structured hierarchically into four levels. At the top level, there are two major issues: the environmental quality of the building (Q), and the environmental load reduction of the building (LR). Assessment categories included in Q are: Indoor Environment, Quality of Service, and Outdoor Environment on Site, whilst those included in LR are: Energy, Resources & Materials, and Off-site Environment. Under these six major categories, there are criteria and sub-criteria. For assessment of offices, there are six criteria and 50 sub-criteria. Different criteria and sub-criteria are used for different building types. For assessment of building complexes, the overall result is weighted according to the floor area of each building type.

The numeric scoring system is used. For scoring of the sub-criteria a scale from 1 to 5 is used, where 1 represents the minimum conditions required by laws and regulations and 3 is considered an average score. A score of 5 represents a level of performance that considerably exceeds the current target. CASBEE adopts mainly non-linear performance-based criteria for each scoring level. For scoring items for which performance levels cannot be easily defined (e.g., efforts to ensure maintenance management, provisions of communications and IT equipment, etc.), points are awarded according to the features specific criteria. Aggregated points are used to determine the scoring level.

The weighting coefficients for different levels of assessment items were determined by a questionnaire survey of opinions of experts. Weighting coefficients for each category, criteria and sub-criteria level add up to 1.0. Scores for each assessment item are multiplied by the weighting coefficient, and aggregated into a SQ (score for Q issues); and a SLR (score for LR issues). Scores at category and issue levels, after applying the weighting coefficients, remain in a scale of 1 to 5. Assigning separate scores to SQ and SLR is a special characteristic of CASBEE, which enables calculation of the overall assessment metric, called Building Environmental Efficiency (BEE), according to the formula below, to reflect environmental implications:

$$\mathrm{BEE} = \frac{Q}{L} = \frac{[25 \times (\mathrm{SQ} - 1)]}{[25 \times (5 - \mathrm{SLR})]}$$

It can be seen that scores for Q (Building environmental quality and performance) and L (Building environmental loadings) are obtained by multiplying SQ, as well as SLR, by 25, so that the Q and L scores will fall within 1 to 100. Furthermore, Q and L values are plotted on the Y- and X-axis of a graph to determine the BEE position, which enables determination of an overall environmental impact on a scale of Poor (BEE < 0.5), Fairly Poor (BEE = 0.5 to < 1.0), Good (BEE = 1 to <1.5), Very Good (BEE = 1.5 to <3.0, and Q < 50), and Excellent (BEE > 3.0, and $Q \geq 50$).

CASBEE for New Construction allows assessments to be made at each stage of a building's design and construction phases (Preliminary Design, Execution Design, and Construction Completion). Certifications are by reference to design specifications and predicted performance. Certification results remain valid for three years commencing from the completion of construction. Recertification requires assessment against the latest edition of CASBEE for Existing Building.

2.4. BEAM Plus

The Hong Kong Building Environmental Assessment Method (BEAM Plus) is a voluntary scheme first launched in December 1996 (formerly known as HK-BEAM). The original BEAM Plus scheme comprised two versions, one for new (HK-BEAM 1/96) and the other for existing office buildings (HK-BEAM 2/96). It covered a wide range of issues related to impacts of buildings on the environment in terms of global, local and indoor scales. The most current BEAM Plus documents were released in 2010 (Versions 1.1 for New Buildings and Existing Buildings) to address implementation problems experienced and to expand the range of building types that the scheme can cover [33].

The key criteria and features of BEAM Plus for New Buildings are structured hierarchically in three levels. The credits scoring system is adopted. At the top level, there are six major issues (maximum number of credits in parentheses): Site Aspects (22 + 3B), Material Aspects (22 + 1B), Energy Use (42 + 2B), Water Use (9 + 1B), Indoor Environmental Quality (32 + 3B) and Innovations and Performance Enhancement (1 + 5B). Here, "B" stands for bonus credits. For assessment of offices, there are 23 categories and 88 criteria under the six major issues. Different criteria are used for different building types. BEAM Plus also allows assessment of a mix of building types in a complex.

BEAM Plus adopts the credits scoring system. Credits are awarded on the six issues according to performance or feature specific criteria. These credits are then added together to produce a final score, which is compared against a scale for determining an overall grade; bronze (≥40% credits), silver (≥55% credits), gold (≥65% credits) and platinum (≥75% credits). Furthermore, to qualify for the award, it is necessary to obtain a minimum percentage of credits for Site Aspects (SA), Energy Use (EU), Indoor Environmental Quality (IEQ), and Innovation (IA). For the performance based criteria, depending on the characteristics, both linear and non-linear scoring scales are adopted.

The weighting system for compliance with different issues were determined by making reference to similar assessment methods operating elsewhere, as well as surveys and informed opinion of those who have contributed to the development of BEAM Plus [34].

BEAM Plus for New Buildings is designed to make assessments at each stage of a building's design and construction (Preliminary Design, Detailed Design, and Construction Completion). Certifications are issued on the basis of design specifications, predicted performance, and actions taken during construction, upon completion. As a significant proportion of credits is based on actions taken, certification can only be issued upon construction completion and results are valid for five years. Recertification requires assessment based on the latest edition of BEAM Plus for Existing Building.

2.5. ESGB

In China, green efforts began in the early 1980s, in response to the continuous increase in energy use of the residential sector, particularly for air-conditioning and heating. Promulgated by the Ministry of Construction (MOC), the "Evaluation Standard for Green Building (GB/T 50378-2006)" was issued in March 2006 [35]. It is a voluntary scheme used to assess environmental performance of all residential and commercial buildings (commercial buildings include office buildings, hotels, shopping malls, etc.). The scheme (abbreviated as ESGB) is administered by China's Green Building Office (GBO) established in April 2008. Up to June 2009, ten buildings had been successfully certified by ESGB [36].

Assessment items in ESGB are structured in two levels, Categories and Criteria, which is similar to Issues and Categories levels of other schemes. Under each performance category, there are three levels of compliance criteria: Baseline, Average and Advanced. ESGB for residential buildings comprises 27 criteria at baseline level, 40 at average level, and 9 at advanced level, whilst for commercial buildings it comprises 26 criteria at baseline level, 43 at average level, and 14 at advanced level. The points scoring system is adopted. The six performance categories (number of average and advanced points in parentheses) for ESGB Commercial Buildings are: Sustainable Site & Outdoor Environment (6 and 3), Energy Use (10 and 4), Water Use (6 and 1), Material Use (8 and 2), Indoor Environmental Quality (6 and 3), and Operation management (7 and 1). ESGB adopts both performance-based and feature specific criteria. Feature-specific criteria are mostly cross-referenced to National Standards (GB Standards and Regulations).

Points are awarded separately for each performance category on compliance with the average and advanced criteria. Aggregated points under each performance category are used to determine the rating level. The rating system is in accordance with the number of points earned (rounded from the percentage of points) from the applicable average and advanced criteria. The overall grade is on a scale of 1-Star (average points ≥33%), 2-Star (average points ≥67%, advanced points ≥33%) and 3-Star (average points ≥80%, and advanced points ≥67%). As a pre-requisite for obtaining a ranking, full compliance with all baseline criteria is required.

ESGB is designed for assessments of new buildings, newly built extensions to existing buildings, and major refurbishments at each stage of a building's design and construction phases (Preliminary Design, Detailed Design, and Construction Completion). Certification requires submission of design specifications, predicted performance, and actual performance data. Certification can be issued only one year after construction.

3. Schemes comparison

Table 1 summarizes the history, assessment scope, building sectors covered, the rating system and the certification method of the five schemes reviewed above. The schemes can be used to assess multiple types of buildings and at different stages of development. Several revisions have already been made since they were launched. To enable comparisons are conducted on the same basis, the latest version of each of the five schemes for new commercial buildings was evaluated in detail. New commercial buildings were chosen because they collectively account for the greatest amount of resources consumption and environmental emissions, and are thus the first building type targeted by most schemes. Accordingly, the evaluation is based on BREEAM 2011 for New Construction: Offices, LEED for New Construction 2009, CASBEE for New Construction 2010 Edition, BEAM Plus for New Buildings 2010, and ESGB for Public Buildings 2006. Hereafter, they will be simply referred to as BREEAM, LEED, CASBEE, BEAM Plus and ESGB.

3.1. Assessment scope

As shown in Table 1, BREEAM (114) has the highest number of criteria, followed by LEED (107), BEAM Plus (88), ESGB (80), and CASBEE (50). Since a higher number of criteria/sub-criteria may give the impression that the scope of environmental aspects covered is wider, the scope of assessment of the five schemes has been compared to verify if this is a valid assumption. Given that the major assessment aspects of the five schemes are structured in different formats, the assessment aspects of SBTool was generally adopted as a common basis for this comparison. Table 2 shows the detailed comparison. A summary of all categories assessed in the five schemes together with indications of whether each of them is assessed under the five schemes is given in Table 2 for comparison.

It can be seen that BREEAM, LEED and BEAM Plus have the widest scope, covering 19 key assessment aspects, whilst CASBEE is the narrowest, which covers only 15 aspects. ESGB covers 17 key aspects, and their scopes of coverage are comparable.

Attempts have been made to identify the correlation between the number of criteria/sub-criteria and the number of key assessment aspects. A strong correlation was observed ($r^2 = 0.86$), confirming that the assumption made earlier that the number of criteria/sub-criteria can reflect the scope of assessment aspects amongst schemes is valid.

Amongst the five schemes, common assessment items can be seen in five aspects: Sustainable Site (i.e. Site Suitability and Development), Energy and Resource Consumption, Indoor Environmental Quality, Materials Use and Water Use. Other than these five aspects, the coverage varies amongst the five schemes.

A number of sustainability aspects addressed by SBTool only are not covered by any of the other five schemes (Table 2). These include social and economic, as well as cultural and perceptual aspects. On the other hand, transport is included in BREEAM, LEED and BEAM Plus but not in SBTool and other schemes. BREEAM considers management, pollution and waste as individual assessment aspects, but the other schemes do not assign them the same level of importance, and have included them as assessment categories in other major issues.

For assessment of building energy efficiency, scopes of all the five schemes are fairly comprehensive; from outdoor environment to indoor environment, from global aspects to local aspects, and from design aspects to operational aspects. All the five schemes have explicitly spelt out assessment of commissioning of building energy systems, which, according to studies, is considered a good practice to ensure more marketable, and sustainable buildings [37]. However, only BEAM Plus and ESGB include peak electricity demand in their assessment; BREEAM, LEED and CASBEE do not.

On other aspects, only LEED and CASBEE included heat island effect under site selection. CASBEE also introduces a different tool (CASBEE-HI) to assess the efforts made to alleviate the heat island phenomenon [38]. Furthermore, there are separate LEED versions for assessing different stages of the building lifecycle, but the other five schemes assess various stages of a project – pre-design,

Table 1
History and metrics of five schemes.

	BREEAM	LEED	CASBEE	BEAM Plus	ESGB
History					
First version	1993	1998	2002	1996	2006
Latest version	2011	2009	2010	2010	2006
Assessment scope					
Issues	10	7	2	6	9
Categories	69	107	6	23	80
Criteria	114	–	6	88	–
Sub-criteria	–	–	50	–	–
Building types					
New	O	O	O	O	O
Interiors	–	O	–	–	–
Core and shell	O	O	–	–	–
Existing	O	O	O	O	O
Renovated	O	O	O	O	–
Mixed-use	O	O	O	O	–
Rating system					
Approach	Simple additive	Simple additive	Weighted	Simple additive	Weighted
Scoring system	Credits	Points	1 to 5	Credits	Points
Rating level	Overall grade	Overall grade	Environmental impact	Overall grade	Overall grade
	Pass	Certified	Poor	Bronze	1-star
	Good	Silver	Fairly poor	Silver	2-star
	Very good	Gold	Good	Gold	3-star
	Excellent	Platinum	Very good	Platinum	
	Outstanding		Excellent		
Certification Method					
Pre-design	O	O	O	O	O
Design	O	O	O	O	O
Construction	O	O	O	O	O
Operations	O	–	–	–	O
Performance data	O	–	–	–	O
Occupation period (years)	Not specified	n/a	n/a	n/a	1
Validity (years)	n/a	5	3	5	n/a
Certification phases	1	2	2	2	1

design, construction and occupation – in a single version. All the five schemes allow for different assessment categories for different building types and stages of construction.

Evidently, owing to the need to address issues in local contexts of individual countries or regions, there are differences in assessment issues and categories amongst the schemes. For example, ESGB includes an explicit assessment of peak electricity demand because power shortage is a serious concern in China. According to predictions of the China Electricity Council (CEC), the shortage is about 5000 MW, and had gone up to 6000 MW during the summer peak period in 2007 [39]. BEAM Plus also assesses peak electricity demand with a view to delay further expansion of generation, transmission and distribution capacity. This assessment was necessitated by the unique situation of the power sector in Hong Kong, where only two companies have the right to generate, distribute and sell electricity (each to different parts of Hong Kong). Electricity price is regulated by the Hong Kong SAR Government on the basis of permitted maximum annual return on assets value of the electricity companies. Therefore, the two power companies have the incentive to encourage consumers to increase electricity consumption [40].

Minimization of lifecycle energy use is encouraged in BEAM Plus by including assessment of embodied energy use. This is related to the fact that Hong Kong has hardly any indigenous energy resources; nearly all the energy it consumes has to come from imported fuels. Similarly, most raw building materials and products are imported from overseas to account for a significant portion of the embodied energy use of buildings. However, inclusion of lifecycle energy assessment in BREEAM is for a somewhat different consideration. Under the Kyoto protocol, UK, as part of the European Union (EU), has to meet the targeted 8% cut in GHG emissions from 1990 levels, in addition to a further 4.5% cut for the UK itself [41]. The UK Government has set a more ambitious domestic goal, viz. a 20% reduction in carbon emissions by 2010. The Energy White Paper (2003) even targeted a 60% cut by 2050. Additionally, materials consumption of the construction industry in the UK amounts to around 6 tonnes of material per person per year, which is the highest amongst all industries [42].

For addressing regional needs, the new addition of Regional Priority credits (RPC) by LEED is worth-noting. The RP credits are awarded in the form of bonus credit to encourage pursuing measures with environmental importance for a project's region.

3.2. Relative weights of assessed issues

A comparison of relative contributions of assessments on major issues to the overall assessment in the five schemes is summarized in Table 3. It can be seen that energy efficiency is the most dominant issue in all the five schemes, which account for, on average, 27% of the total score, followed by sustainable site and indoor environmental quality. They account for 19% of the total score. Materials and water use account, on average, for 12% and 9% of the total score, respectively.

Correlations of weights as well as correlations of ranks of weights (1 = highest weight; 5 = lowest weight) assigned in each pair of schemes to the five common issues were analyzed using the bivariate correlation feature in SPSS, which helped unveil the similarity between the compared schemes in weights and ranks of weights given to various issues. The correlation coefficients, significance levels, and the absolute value of the proximity correlation coefficient ($\overline{R_X^2}$) of each scheme determined by Eq. (1) are shown in Table 4.

$$\overline{R_X^2} = \sum \frac{r^2}{(m-1)} \quad (1)$$

Table 2
Assessment scope of the five schemes (by reference to SBTool).

Scope	SBTool	BREEAM	LEED	CASBEE	BEAM Plus	ESGB
Site suitability development						
Site suitability	O	O	O	O	O	O
Urban design and site development	O	–	O	O	O	O
Energy and resource consumption						
Total life cycle primary non-renewable energy use	O	O	–	O	O	–
Electrical peak demand	O	–	–	–	O	O
Environmental loadings						
Greenhouse gas emissions	O	O	O	O	O	O
Other atmospheric emissions	O	–	–	–	–	–
Other local and regional impacts	O	O	O	–	–	O
Materials use						
Materials	O	O	O	O	O	O
Solid wastes	O	O	O	O	O	O
Water use						
Potable water	O	O	O	O	O	O
Impacts on site	O	O	O	–	–	O
Rainwater, storm water and wastewater	O	–	O	–	–	O
Indoor environmental quality						
Indoor air quality	O	O	O	O	O	O
Ventilation	O	O	O	O	O	O
Air temperature and relative humidity	O	O	O	O	O	O
Daylighting and illumination	O	O	O	O	O	O
Noise and acoustics	O	O	O	O	O	O
Service quality						
Safety and security during operations	O	O	–	–	O	–
Functionality and efficiency	O	–	–	–	O	–
Controllability	O	O	O	–	–	–
Flexibility and adaptability	O	–	–	O	–	–
Optimization and maintenance of operating performance (including testing and commissioning)	O	O	O	O	O	O
Social and economic aspects						
Cost and economics	O	–	–	–	–	–
Social aspects	O	–	–	–	–	–
Cultural and perceptual aspects						
Culture and heritage	O	–	–	–	–	–
Perceptual	O	–	–	–	–	–
Others						
Renewable energy	–	O	O	O	O	O
Transportation	–	O	O	–	O	–
Heat island effect	O	–	O	O	–	–
Management	O	O	–	–	–	–
Total	28	19	19	15	19	17

where r is the correlation coefficient of one scheme with other schemes, X is the scheme number (=1 to 5), and m is the number of schemes (5 in this study).

The proximity correlation coefficient is to indicate the proximity of one scheme and other schemes – the higher the value; the closer the link. It is noted that the computed $\overline{R_X^2}$ both for weights and ranks of weights amongst the five schemes are between 0.592 and 0.962, whilst the significance levels are between 0.293 and 0.009. Although there is no definite baseline coefficient to indicate a strong correlation, it is generally accepted that a coefficient of 0.5 is of moderate magnitude [43], and can be regarded as a moderate correlation. Thus, consensus is considered moderately reached on weights and ranks of weights allocated for different assessment aspects by the five schemes.

It can also be seen that from the integral proximity coefficient that weights and rankings of weight adopted by ESGB correlate strongly with the other four schemes to indicate they are typical amongst the other schemes.

3.3. Rating system

It can be seen under Assessment Scope in Table 1 that BREEAM and BEAM Plus are structured in three levels, LEED and ESGB in two levels, and CASBEE in four levels. In the scoring system (under

Table 3
Weighting coefficients comparison.

Scheme	Site Suitability and urban development	Energy and resource consumption	Water use	Indoor environmental quality	Materials use	Others
BREEAM	10%	19%	6%	15%	13%	38%
LEED	25%	33%	9%	14%	9%	9%
CASBEE	24%	29%	2%	21%	12%	13%
BEAM Plus	18%	30%	15%	25%	12%	0%
ESGB	18%	26%	11%	18%	16%	12%
Max	25%	33%	15%	25%	16%	38%
Min	10%	19%	2%	14%	9%	0%
SD	6%	5%	5%	4%	3%	14%
Average	19%	27%	9%	19%	12%	14%

Table 4
Bivariate correlation analysis on weights and ranks of weights.

Scheme		Correlation coefficients (r)					$\overline{R_X^2}$
		BREEAM	LEED	CASBEE	BEAM Plus	ESGB	
BREEAM							
Weights	r	1	.592	.784	.763	.907	0.592
	Sig.		.293	.117	.134	.034	
Ranks of weights	r	1	.606	.700	.700	.770	0.485
	Sig.		.278	.188	.188	.128	
LEED							
Weights	r	.592	1	.865	.742	.875	0.604
	Sig.	.293		.059	.151	.052	
Ranks of weights	r	.606	1	.970	.849	.910	0.714
	Sig.	.278		.006	.069	.032	
CASBEE							
Weights	r	.784	.865	1	.763	.916	0.696
	Sig.	.117	.059		.133	.029	
Ranks of weights	r	.700	.970	1	.800	.962	0.749
	Sig.	.188	.006		.104	.009	
BEAM Plus							
Weights	r	.763	.742	.763	1	.821	0.597
	Sig.	.134	.151	.133		.088	
Ranks of weights	r	.700	.849	.800	1	.866	0.650
	Sig.	.188	.069	.104		.058	
ESGB							
Weights	r	.907	.875	.916	.821	1	0.775
	Sig.	.034	.052	.029	.088		
Ranks of weights	r	.770	.910	.962	.866	1	0.774
	Sig.	.128	.032	.009	.058		

Rating System), CASBEE adopts numeric scores, BREEAM and BEAM Plus adopt credits, and LEED and ESGB adopt points. It is not surprising to see BREEAM and BEAM Plus, as well as LEED and ESGB, share the same hierarchical structure and scoring system because BREEAM was the reference model for developing BEAM Plus [44]. The same applies to LEED and ESGB [45]. With regard to CASBEE, it is understood that the one additional hierarchical level (sub-criteria level) is linked to use of the BEE rating system.

The hierarchical structure of an individual scheme is primarily a way to systematically organize the large number of diverse assessment items. Amongst the five schemes, CASBEE applies weighting coefficients to different assessment levels in calculation of the final score. ESGB also structures assessment items into two compliance levels. As such, each assessment item has different levels of influence on the final score. The advantage of this weighted approach is that it allows each item to be assessed on a common scale. BREEAM, LEED and BEAM Plus, on the contrary, apply a simple additive approach where weights of different assessment items are accounted for by the maximum number of credits assigned to individual items. Hence, there are basically two hierarchical approaches–with and without weighting coefficients.

For hierarchical approach with weighting coefficients, the determination of the final score (S) can be expressed mathematically by Eq. (2):

$$S = \sum_{i=1}^{N}(w_i(\sum_{j=1}^{p_i} a_{ij}S_j)) \quad (2)$$

where w_i = weighting coefficient (%) applied to the ith category (from 1 to N); and $\sum_{i=1}^{N} w_i = 1$; a_{ij} = weighting coefficient (%) applied to the jth constituent criterion (from 1 to P_i) under the ith category; and $\sum_{j=1}^{p_i} a_{ij} = 1$; and S_j = the score of the jth criterion.

Note that w_i and a_{ij} were determined according to the importance of each category and criteria on the total assessment.

Whilst for hierarchical approach without weighting coefficients, one credit will be awarded on fulfilling the specified requirements. All assessment criteria can be assumed of equal weighting. The determination of the final score (S) can be expressed mathematically by Eq. (3):

$$S = \sum_{i=1}^{N}(\sum_{j=1}^{p_i} P_{ij}) \quad (3)$$

where p_j is the jth fulfilled criterion (from 1 to P_i) under the ith category (from 1 to N).

However, considering that consensus is found moderately reached amongst the five schemes on weights and ranks of weights allocated for different issues, it can be concluded that the two hierarchical approaches – weighted or simple additive, and the three scoring systems, numeric scores, points and credits – are basically the same.

It can also be seen in Table 1 that different rating systems with different formats of assessment outcomes are used by all the five schemes. Irrespective of whether the outcome format is numeric score (from 1 to 3-star), overall grade or environmental impact approach (from passed to outstanding; and from bronze to platinum), the certified building will still be classified into different rating levels according to the percentage of score earned. To enable an evaluation, the score for different performance levels (S_x) were normalized as a percentage of the maximum achievable value (S_{MAX}) to become scoring (S_y) and the corresponding rating (R_y) levels. S_y and R_y are shown mathematically below:

$$S_y = \frac{S_x}{S_{MAX}} \times 100\% \quad (4)$$

S_x is the required no. of final score (S) for achieving the yth rating level (y = 1 to N).

$$R_y = \frac{100\%}{N} \times y \quad (5)$$

where N is the number of performance levels.

The normalized rating systems are summarized in Table 5 and compared in Fig. 1. In Fig. 1, it can be seen that in BREEAM and

Table 5
Summary of rating and scoring levels.

Rating level (%)	Scoring level (%)				
	BREEAM	LEED	CASBEE	BEAM Plus	ESGB
0	30	37	12.5	40	16.5
20	45		12.5		
25		47		55	
33					50
40	55		25		
50		56		65	
60	70		50		
67					73.5
75		75		75	
80	85		75		
100	100	100	100	100	100

ESGB, the rating level is in general linearly related to the scoring level, whilst a non-linear rating scale is adopted by LEED, CASBEE and BEAM Plus.

There are two types of non-linear rating scales – concave and convex. A convex scale indicates that the marginal rate of increase in the rating level increases with unit increase in the scoring level, whereas for a concave scale, the marginal rate of increase in the rating level decreases with unit increase in the scoring level. It is noted that LEED, CASBEE and BEAM Plus adopt a concave scale.

There is at present little discussion in the public domain on requirements of a satisfactory rating system. However, it has been widely accepted that the success of a voluntary scheme depends mainly on how well the scheme is received by the profit-maximizing building owners and developers. Also, there is an emerging notion that the rating scale should be used to acknowledge implementation cost and difficulties [4,7]. The underlying premise is that investors would like to be rewarded in proportion to the effort made in achieving a higher level of environmental performance. According to the law of diminishing marginal returns in economics, it is logical to award proportionally higher ratings to encourage investors to aspire for a higher level of environmental performance under the voluntary scheme. In this connection, a convex scale is considered a better rating system. It can be seen in the above that all five schemes did not take into consideration such a phenomenon in developing their rating system.

With regard to the rating scales, a closer review of the five rating systems indicates that CASBEE is the most relaxed as it requires the lowest scoring level for certification (=12.5%) whilst BEAM Plus is the most stringent as it requires the highest scoring level (=40%). For the same scoring level, CASBEE constantly awards

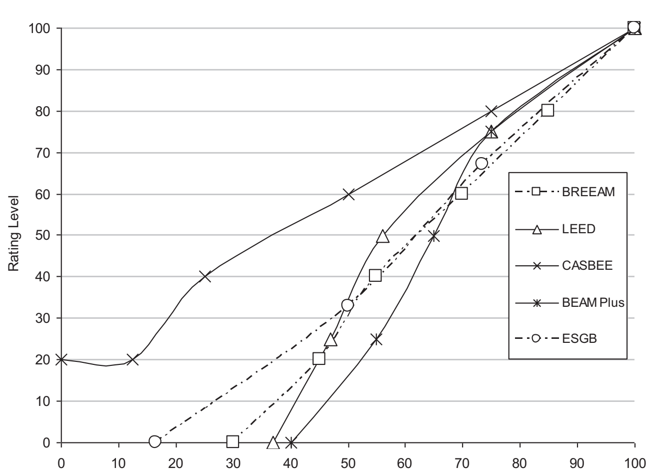

Fig. 1. Rating scale comparison.

higher overall ratings than other schemes. BEAM Plus is relatively tough in this aspect. BEAM Plus gives the lowest overall rating for a score of sixty-five or less; and for a score of sixty-five or higher, ESGB and BREEAM gives the lowest overall rating. LEED adopts a rather moderate rating scale. Coincidently, LEED and BEAM Plus, BREEAM and ESGB require the same scoring levels to achieve the highest rating level (scoring level ≥75%).

It is worth noting that although CASBEE appears to be more relaxed in rating scale, a building in Nagoya, Japan, awarded the highest rank in CASBEE certification, also received the equivalent of LEED Platinum certification [46]. LEED appears to be less stringent in rating scale than BREEAM, but BREEAM awards higher rating for the same building than LEED [4,47]. There are discussions on whether the rating system should be designed to reward only buildings that meet the best practices or for buildings that barely meet regulations, to promote change [10,48]. The assessment experience indicates that simply by making reference to rating systems, without taking into account the performance criteria and local context, one cannot tell the actual performance of certified buildings. An earlier study by the author has conducted a side-by-side comparison of the energy assessments of the five schemes. The results indicated that LEED was the most stringent and inflexible approach [49].

3.4. Certification method

Whether certification should be based on the actual performance, design figures, predicted performance, or a combination of all of them remains a controversial topic [15,23,50]. Questionnaire survey results [13] indicate that the use of "actual performance" is favoured by half of the respondents (=50%) who opined that the use of actual performance data was fairer. The votes for the other three options were 25%, 10% and 15%, respectively.

A comparison of certification practices of the five schemes (Table 1) shows that BREEAM and ESGB adopt a one-phase certification arrangement, which covers assessments during various phases of a development project, including pre-design, design, construction and operations. Certification can be obtained during the operations phase only, by reference to design specifications, predicted performance, and actual performance data. However, LEED, CASBEE and BEAM Plus adopt a two-phase certification arrangement where assessment can be made in the pre-design, design and construction phases, but not the operations phase. Certifications are based on design figures and predicted performance; submission of actual performance data is not required. They alternatively introduced a recertification requirement within a period of three to five years from the last certification. Recertification requires assessment according to the latest version for Existing Buildings, on the basis of actual performance data.

The above indicates that all five schemes eventually assess the actual building performance. Hence, the differences are not related to the data used for certification, as perceived by some who have discussed this in extant literature, but is on whether one-phase or two-phase certification arrangement is used.

A review of the latest versions of the five schemes indicates that despite BREAM In-Use is under preparation [51], BREEAM and ESGB currently do not have separate versions for existing buildings. It is logical for them to adopt the one-phase certification arrangement to ensure the predicted performance can be achieved. However, under LEED, CASBEE and BEAM Plus, there is an option for building owners to decide whether to pursue recertification of their existing buildings.

According to LEED, the use of two-phase certification arrangement provides flexibility to developers having different levels of control over building design, construction and tenants fit-out. This is of particular concern to buildings developed for leasing. Hong Kong is one typical example where most built-up areas are occupied by tenants. Therefore, use of two-phase certification arrangement is more appropriate in such cases.

However, one common complaint about the two-phase certification arrangement is the disconnect between actual building performance and design-phase modelling. Many studies advocate use of one-phase certification arrangement which extends to at least one year after the building is occupied to ensure certified buildings deliver anticipated performance [51,52].

The major strengths of voluntary building environmental assessment schemes are that they encourage good environmental practices beyond the current industry practices and offer flexibility for developers in reaching this target [7,19]. As long as the actual building performance is eventually assessed, the key concern is the certification method that can provide flexibility to developers in ensuring performance in different phases of the life cycle of a certified building is better than industry practices. In this respect, the two-phase certification method adopted by LEED, CASBEE and BEAM Plus is the preferred approach.

4. Conclusion

Evaluations on the metrics of the five assessment schemes suggest that although BEAM Plus was modelled from BREEAM, and ESGB was reportedly to be based on LEED, with years of development, besides the hierarchical approach and the scoring system adopted, their links to their respective origins become less and less apparent. Nonetheless, the five schemes seem to have evolved along similar directions.

In respect of assessment issues and categories, BREEAM and LEED have the widest scope whilst CASBEE has the smallest. The number of assessment criteria/sub-criteria was found correlated with the scope of assessment. It is noted that each scheme appreciates different assessment issues differently and their respective scopes acknowledge the local contexts.

With regard to use of linear and non-linear rating scales, it was found that convex non-linear rating scale is more suitable for awarding proportionally higher rating for efforts made by investors to achieve a higher level of performance. Despite non-linear rating scales having been adopted by LEED, CASBEE and BEAM Plus, none of them is convexly-curved. The rating scales are therefore recommended to be revised according to the law of diminishing marginal returns.

Different schemes use different certification arrangements, i.e. either single-phase or two-phase. Single-phase certification arrangement can ensure connect between actual building performance and design-phase modelling, whilst the two-phase certification method can provide the flexibility required by developers for ensuring performance in different phases of the life cycle of a certified building that is better than industry practices. In this connection, as long as actual building performance will eventually be assessed, two-phase certification method adopted by LEED, CASBEE and BEAM Plus is considered the preferable approach.

Through statistical analysis, it was found that consensus has been moderately reached on weights and ranks of weights allocated for different assessment aspects of the five schemes, and the weights adopted by ESGB was considered typical, i.e. sustainable site (18%), energy and resource consumption (26%), water use (11%), indoor environmental quality (18%), and materials use (16%).

The strengths and characteristics of the five representative schemes revealed from this study provides policy makers with useful information for development of domestic schemes that can address specific needs and concerns of individual regimes. Future coordination and sharing of research efforts across the world for the evolvement of a better scheme can also be achieved based upon recommendations of this study.

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